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AN INTRODUCTION TO
SELF-INDUCED RAINOUT

C. R. Molenkamp

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**LAWRENCE
LIVERMORE
LABORATORY**
University of California Livermore

MASTER

LAWRENCE LIVERMORE LABORATORY

University of California Livermore, California 94550

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ABSTRACT

Self-induced rainout is the rapid scavenging and deposition of radioactive weapons debris by a precipitating convective cloud. It is caused by detonation of a nuclear weapon. Results from a theoretical calculation using a cloud scavenging model indicate that self-induced rainout can occur in appropriate atmospheric conditions. Observational evidence from Hiroshima and Nagasaki indicate that self-induced rainout may have occurred in those cities.

For the past six years we have been involved in a rainout research program to assess the potential collateral damage due to rainout in a tactical context. Three major components of our research are

● Studies of the microphysical attachment processes whereby small radioactive debris particles become incorporated in cloud droplets and raindrops,

● Investigation of dynamic interactions between rain clouds and debris clouds that lead to entrainment of debris into regions of precipitation where scavenging and deposition can occur,

● Analysis of scavenging climatology that translates rain frequency and characteristics into estimates of the occurrence and magnitude of deposited radiation doses.

We have concluded from previous research that a militarily significant collateral-damage hazard would occur approximately 10 per cent of the time in Western Europe.[1] As a result of this conclusion, the Army Nuclear Agency is currently incorporating in field manuals a section on rainout collateral damage.

Several years ago we conjectured that detonation of a nuclear weapon could initiate the formation of a convective cloud that would precipitate and rapidly scavenge and deposit a large amount of radioactive debris on the ground. To investigate the consequences of such an occurrence, which we call self-induced rainout, we used a convective cloud scavenging model that we had developed to study scavenging by naturally occurring convective clouds. This model simulates the life cycle of a convective cloud, including the development of rain and the scavenging and deposition of debris. It

operates by numerically integrating with time Eulerian, finite-difference approximations of the equations of motion and thermal energy Development of precipitation is included by solving mass-conservation equations for water vapor and liquid water in several drop-size categories. Interactions of debris particles with drops are represented in the model by a similar set of mass-conservation equations for radioactive debris. Initial conditions used to start the model include a motionless, conditionally unstable atmosphere perturbed with a local bubble of warm air. In simulations of natural convection, this buoyancy perturbation is assumed to arise because of atmospheric inhomogeneity or local heating; for simulations of self-induced rainout, the buoyancy perturbation is assumed to result from the local heating due to detonation of a nuclear weapon. Our simulation of a 1-kt free air burst, using a sounding from Germany on a day when there were scattered convective showers, predicted that self-induced rainout would occur. Radiation dose rate patterns one hour after detonation are given in Fig. 1. Our model confirmed the conjecture that self-induced rainout could occur and could deposit militarily significant amounts of radioactivity on the ground.

Because of this result, we made a cursory look at weapons test data to see if we could find any observations of self-induced rainout, but none were found. This is not particularly surprising, because tests in Nevada were always timed to avoid any early precipitation, as is relatively easy to do in the arid climate of Nevada. In the Pacific there were relatively few low-yield free air bursts. From the observation points, which were typically 10 or more miles upwind of the burst point, we have found no
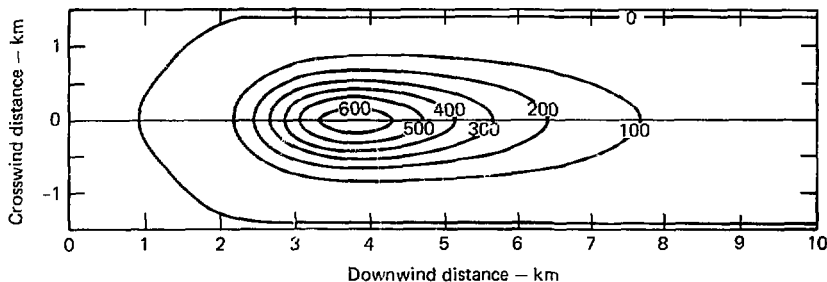
FIG. 1. Radiation dose rate contours on the ground one hour after detonation, assuming a 5 m/s wind. Contour levels are in rads per hour.

reports of early rainout, but that is not surprising either, because no one ever looked for it. It is not likely that rain would have been observed between the typically low cloud bases in the Pacific and the ocean surface from such great distances. There are observations of precipitation being caused by forest fires and agricultural burning, and these observations lend some support to our hypothesis that self-induced rainout could occur.

Last spring we acquired a report by John A. Auxier entitled *Ichiban: Radiation Dosimetry for the Survivors of the Bombings of Hiroshima and Nagasaki*.[2] This report mentions a phenomenon called "black rain." Subsequent investigation of this phenomenon has shown that rainout of fresh radioactive debris occurred at both Hiroshima and Nagasaki. It was not raining at the time of the burst; in fact, one criterion for release of the bombs was visual sighting of the target. Rain started falling about 20-60 min after the time of burst, which is just what convective cloud models predict for the time required by a cloud to develop to the precipitation stage, and rain fell only at locations downwind of the burst point. Rain amounts were large (in fact, there was local flooding at Hiroshima), and rain continued through most of the day. Large amounts of soil and soot were deposited with the rain; hence the name "black rain." An additional important fact is that intense fires raged in the cities all day and into the evening. These fires probably had the effect of forcing development of convective precipitation throughout the day.

Dose patterns of deposited radioactivity as measured by the U.S. team about 60 days after detonation are shown in Figs. 2 and 3. The contours at the center of burst are due to initial neutron-induced radioactivity and gamma rays. The rainout-deposited debris came down several kilometres downwind (west of center of burst at Hiroshima and east of center of burst at Nagasaki) and contained isotopes characteristic of fresh bomb debris. If one uses the $t^{-1.2}$ decay law for this residual radiation, the infinite dose is 1.4 rad at Hiroshima and 30 rad at Nagasaki. The applicability of the $t^{-1.2}$ law to extrapolate doses backwards in time is doubtful because of the large amount of precipitation in the intervening 60 days, including that from a typhoon that passed through the area. Other data from the survey of survivors and their symptoms of radiation sickness suggest that people exposed to rain may have received larger doses. Table I compares the reported nonincidence of radiation effects for a control population of survivors who received initial exposures up to 20 rad with an experimental population who received similar initial exposures and an additional unknown exposure because they were in the rain. Those people who received rainout exposures suffered much higher incidences of radiation effects and reported suffering symptoms characteristic of doses up to 100 rad.
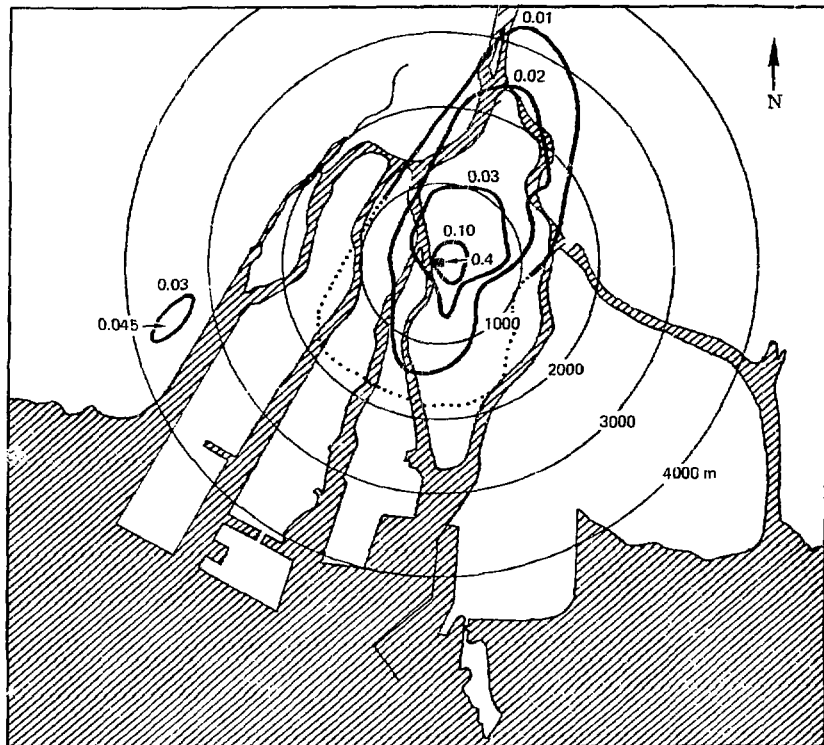
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FIG. 2. Isodose contours evaluated in milliroentgens per hour for October 3-7, 1945, at Hiroshima.[3]

The conclusions we have drawn so far are that rainout of fresh weapons debris occurred at Hiroshima and Nagasaki, that this precipitation was initiated by the weapon itself, by the ensuing fires, or by both, and that doses received by people exposed to rainout were low to moderate.

In the future we intend to continue our analysis of Hiroshima and Nagasaki rainout and weather data and, when sufficient data are available, to simulate these events with our convective cloud scavenging model. Because this scavenging model was not designed to simulate nuclear weapons, several model assumptions are violated in applying the model to these situations. Therefore, we intend to develop a self-induced rainout model that will simulate the rise of a weapons cloud into the ambient environment and the scavenging and deposition of weapons debris. With such a model we will be better able to assess the effects of self-induced rainout in a tactical context.
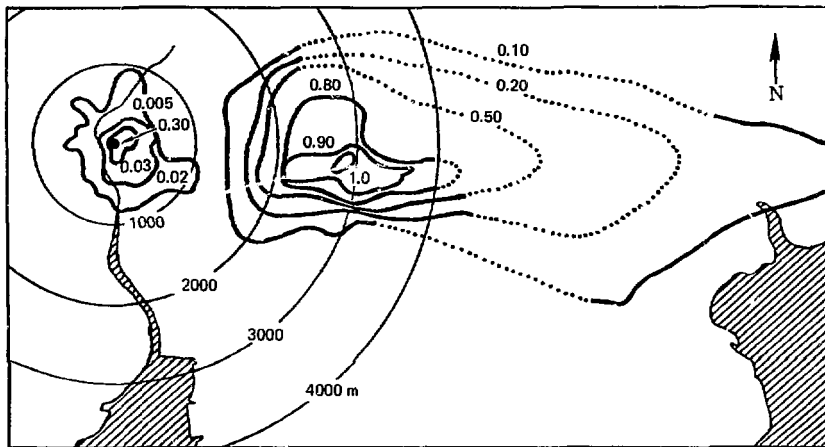
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FIG. 3. Isodose contours evaluated in milliroentgens per hour for October 3-7, 1945, at Nagasaki.[3]

TABLE 1. Reported nonincidence of initial radiation effects.[a]

| Initial exposure, rad | Percent of population reporting nonincidence of initial radiation effects | |
	Experimental population,[b] %	Control population,[c] %
<1	37.8	99.0
1–10	30.6	96.4
10–20	24.4	95.4

[a]Data taken from Ref. 4.

[b]287 survivors who received an initial exposure, as shown in column 1, and an additional unknown exposure because they were in the rain.

[c]16,045 survivors who received only an initial exposure, as shown in column 1, and who were not in the rain.

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